P-113: Ferroelectric LC Aligned on SiO_2 Thin Films Using the Ion Beam Deposition and its Applications

Xihua Li, Anatoli Murauski, and Vladimir Chigrinov,

Center for Display Research, Department of Electrical and Electronic Engineering

Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

A. Khokhlov and E. Khokhlov

Izovac Ltd, Belarus

Abstract

The uniform alignment of Ferroelectric LCs (FLC) on inorganic thin film surfaces can be obtained using oblique ion beam sputtering deposition on substrates. Large deposition angle from 60° to 80 ° can be used for thin SiO_2 alignment layer, which thickness can vary from 5nm to 40 nm. Two types of uniform alignment of "chevron" (before electrical treatment) and "quazi-bookshelf" (after electrical treatment) were studied. The applications using this unique technology in low power consumption displays, fast switching color displays, future LCD-TVs and fiber optics are discussed. High quality alignment on large size substrates is also easily achieved because of the linear design of the ion beam sputtering source, which is a big challenge for FLC on SiO_x layers before.

1. Introduction

Ferroelectric liquid crystals (FLC) have tremendous potentials for production of fast switching electro optical devices for display and other application. Basic problem for FLC is quality and stability alignment in different types devices, compared with nematic type liquid crystals such as TN- or STN- mode because of having layer structures.

It is well understood now that very thin aligning layer is necessary for FLC displays. This has already achieved by our group recently by a photo-alignment technique using a kind of sulfuric azo-dye SD-1 [1-2]. Both perfect optical performance and very fast bistable switching FLC response can be achieved by avoiding mechanical damage and thinning FLC alignment film. The main problems for photo-alignment of FLC displays are photo stability in a short wavelength range and an image sticking phenomenon.

Application of obliquely evaporated SiOx thin films for FLC aligning has already been investigated in late 1980s [3-4]. As high FLC pretilt angles on the surface are induced in this method, the zig-zag defects could be eliminated [4]. Recent progress for FLCDs in this technique was achieved by Citizen Watch Co. Ltd. [5]. The efforts were concentrated on small size displays such as PDA, e-book and watches etc. on glass and plastic substrates. High resolution, very good contrast, fast switching time with memory effect were demonstrated on SiO/SiO2 aligning films using an oblique evaporation technique. However, this evaporation technique can hardly be amenable for FLCD mass production especially for large size substrates.

Compared with SiO_x layer achieved by oblique evaporation technique, thin SiO_2 layers are more reliable using oblique ion beam deposition with large size substrates since ion beam with linear source theoretically has no limitations for oblique sputtering. This technique was used before to align nematic liquid crystal [6-7]. Now, this paper presents the results of investigation of the alignment of FLC materials on the SiO_2 films produced by the ion-beam deposition for LC devices.

2. Experiments

We deposited SiO_2 thin film on ITO-coated glass substrates by using oblique ion beam sputtering system [6-7]. It is based on the anode-layer ion source with the racetrack shape of the discharge area. The SiO_2 films were deposited on the substrates by sputtering the vitreous quartz target by the argon-ion beam. The deposition angle of ions onto the target was determined from the target's normal. The thickness of the SiO_2 coatings was changed by the deposition time and measured by the quartz-crystal controller. We could get good alignment conditions with SiO_2 films with large deposition angle varying from 60^0 to 80^0, while the thickness ranging from 5nm to 40nm.

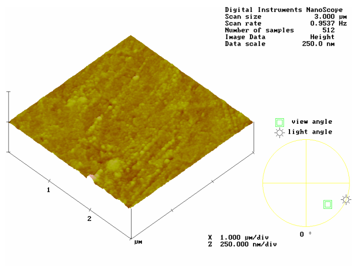
In case of inorganic films, short circuits do not appear even if we do not apply the insulated films. So, the insulated films are not necessary in our case. For the alignment tests, the FLC cells were assembled with antiparallel alignment of SiO_2 layers on two substrates. The cell gap was formed with 2 μm spacers. Chevron structure of FLC material FELIX 017/100 from Clarian was used. FLC material was filled in isotropic phase to empty test cells and in low vacuum condition. After filling, the cells were slowly cooled down with a speed of 2-4^{0}C per minute

3. Results and Discussions

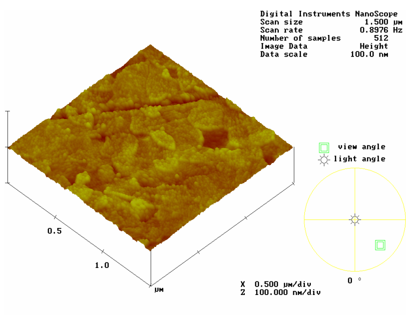
3.1 Properties of the thin SiO_2 layers using oblique deposition technique

Alignment layer was deposited on the rough surface. AFM picture (Fig.1a) shows a profile of SiO_2 layer with a thickness of 40nm that was deposited by linear ion-beam source onto ITO at the angle of 75 degree from normal. Compared with pure ITO surface (Fig.1b), the profile of SiO2 film shows more uniform structure, which implies some anisotropy for FLC alignment.

ISSN/007-0966X/07/3801-0625-$1.00 © 2007 SID



a)

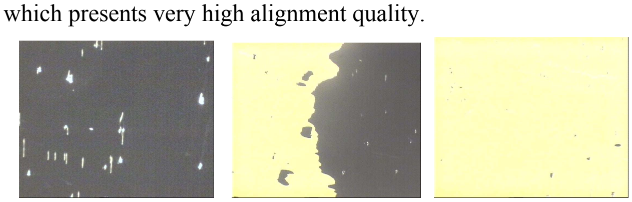


b)

Fig. 1 AFM pictures of example of SiO_2 thin film (Deposition angle: 75^0, Thickness: 40nm) and pure ITO surface

3.2 "Chevron" structure without any electrical treatment and its applications

The occurrence of either C2 or C1 structure for chevron structure FLC materials depends on surface anchoring in such a way that weak anchoring favors the C1 structure and strong anchoring favors the C2 structure [8]. So, uniform C1 structure is more preferred for SiO_2 alignment layer after cooling down. Fig.2 shows the texture of FLC test cells observed under crossed polarizers. Both bright and dark states appear simultaneously, which presents very high alignment quality.



a) b) c)

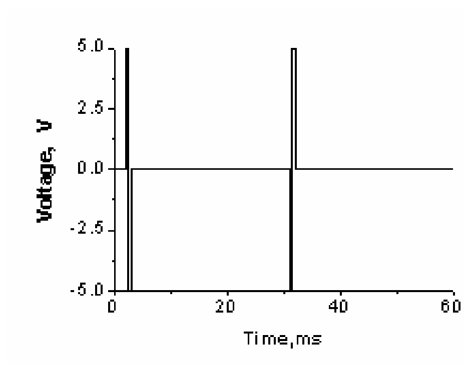
Fig. 2 Textures in different areas of FLC aligned by SiO2 thin films observed under crossed polarizers immediately after cooling

The effective angle corresponds to the half of difference between the extinction angles of the two stable states, which can be evaluated by a polarizing microscope. It depends on the interaction between the alignment layer and FLC layer and characterizes the chevron structure. The measured effective angles ($2\Theta_{eff}$) were almost the same for different deposition angles and thickness of SiO_2 films (~27^0).

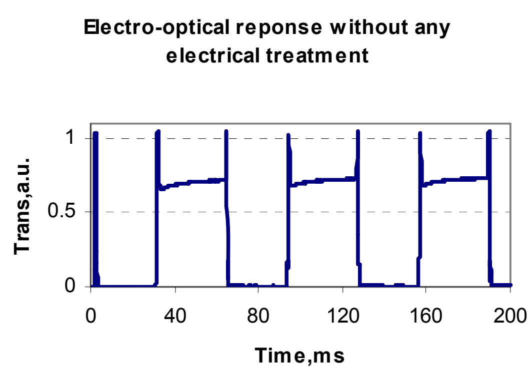
Fig. 3 shows the optical response of FLC on SiO_2 film without any electrical treatment under a binary waveform. The amplitude was 5V with duration time of 1ms for driving waveform. The switching time was less than 150μs, which is much faster compared with nematic LC displays. These significant properties can be used in fast switching of FLC device with small operation voltage, e.g. in field sequential color (FSC) displays.

Fig. 3 Electro-optical response without any electrical treatment under binary waveform with V_{am}=5v and T=1ms

Fig.4b is the electro-optical response of FLC on the SiO_2 thin film under a bipolar switching pulse, which amplitude is 5V and duration time is 1ms (as Fig. 4a).Since C1 structure has much smaller switching cone angle than optimal 45^0, the transmittance of the stable bright state was smaller than the optimal one (Fig.4). The contrast was about 200:1 during bistable switching for the wavelength of 650nm.



a)

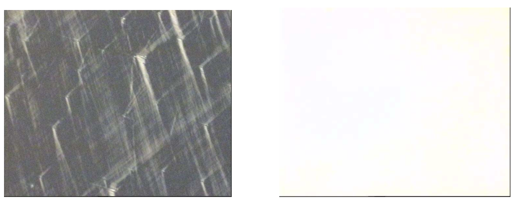


b)

Fig 4. Electro-optical response without any electrical treatment under bipolar switching pulse with Vam=5v and T=1ms

3.3 “Quazi-bookshelf” structure after electrical treatment and its applications

If electrical treatment is applied on the FLC test cells after cooling down, the FLC layer will change from “chevron” to “quazi-bookshelf” structure[9] and show better electro-optics performance because of much larger switching cone angle of Felix materials ($2\Theta\sim45^0$). Electrical treatment was made by applying a square waveform with the amplitude of 10V/μm and frequency of 10HZ on the test cells for several minutes. Fig.5 shows the uniform texture of FLC layer after electrical treatment including dark and bright state, which presents very high quality alignment.



a) b)

Fig 5. Texture of FLC aligned by SiO_2 thin films observed under crossed polarizers after electrical treatment when applied different voltage: a)V_{am}=0; b) V_{am}=15v

Fig.6 illustrates the electro-optical response of FLC cell on the SiO_2 film under bipolar switching pulse with the amplitude of 20V and duration time of 1ms. Since the switching cone angle is optimal, the contrast is larger than 500:1 for 650nm wavelength during bistable switching. Since bistable switching has much better optical performance after electrical treatment, its possible applications in bistable displays such as PDA, or E-book are envisaged. In a binary switching mode, the switching time was almost the same as before treatment (~150us), however, the amplitude was as large as 15V.

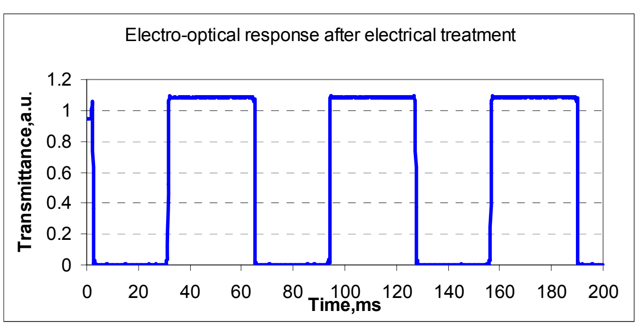


Fig 6. Electro-optical response after electrical treatment under bipolar switching pulse with Vam=20v and T=1ms

An analog gray scale can be generated and stabilized as before treatment for “quazi-bookshelf” structure as we proposed before [10]. Fig.7 shows the TVC dependence of FLC test cells using SiO2 layer of different thickness from 5nm to 40nm, and the oblique deposition angles were 75 degrees. It is possible that enough gray scales can be generated and stabilized when varying the amplitude of writing pulse (0~12V) with duration time of 1ms. Thicker SiO_2 films seem preferred since more gray scales can be addressed and stabilized, which is very promising for microdisplay such as FLC LCOS because of good color, very fast bistable switching, and total photo protection etc. It is also very good for low power consumption FSC LCD-TV in the future, since it is very easy to achieve good alignment for large size substrates and much faster switching speed compared with traditional nematic LCDs.

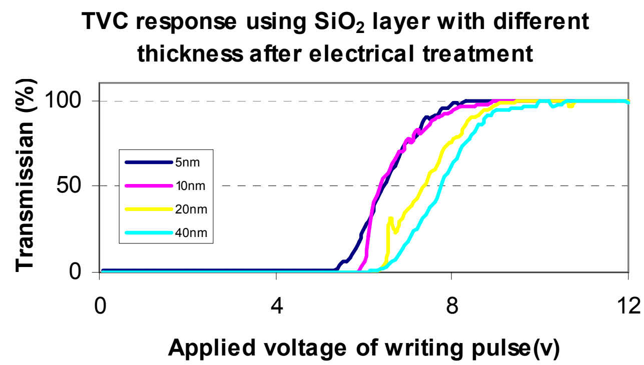
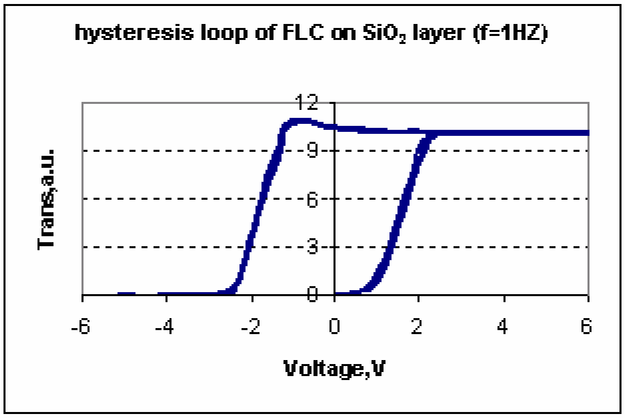
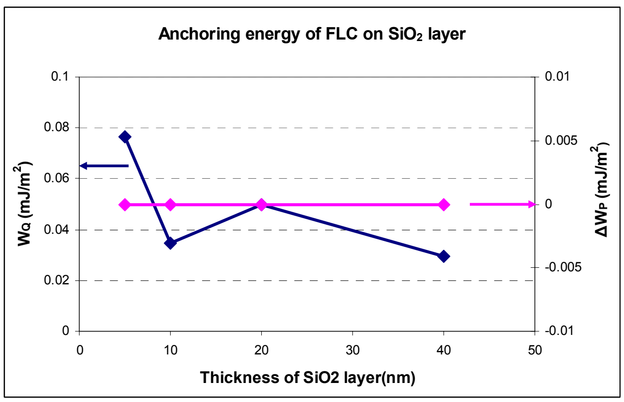


Fig 7. TVC dependence of FLC cells aligned by SiO_2 films with different thickness (Deposition angle: 75^0)

Anchoring properties were also investigated [11] for different SiO_2 films to elucidate the effect of thickness created by the deposition on the alignment quality of FLC (Fig.8b). The center of hysteresis loop is no shift even for low frequency as Fig.8a shows. The dispersion anchoring is almost the same ($10^{-6}\sim10^{-5}$ J/m^2) and there is no difference of polar part for two surfaces in the FLC cells. It proves that there will be no sticky image effect for our display.



a) Hysteresis loop when triangle waveform applied



b) Anchoring properties

Fig 8. Dispersion anchoring (W_Q, left) and polar difference part (ΔW_P, right) of FLC aligned by SiO_2 films of different thickness (Deposition angle: 75^0) using hysteresis loop measurement

4 Conclusions

Thin SiO_2 layers using oblique sputtering deposition technique has great promise for aligning ferroelectric liquid crystal materials. It provides uniform alignment with high contrast bistable switching and very fast switching time. Two types of alignment "chevron" (before treatment) and "quazi-bookshelf" (after treatment) were obtained. Optimization of technological parameters and angle deposition was performed on test cells. Finally alignment quality was checked and developed in passively driving display with size of 160×160 pixels and large substrates.

FLC aligned by SiO_2 layers is the best solutions for low power consumption display (PDA, cell phone, watches), fast switching display (LCOS), future FSC LCD-TV, and fiber optical elements etc. We will continue to develop the unique displays by using FLC and the new deposition techniques.

5 Acknowledgements

This research was supported by RGC grant HKUST 6149/04E and HKUST CERG612406..

6. References

[1] E. Pozhidaev, V. Chigrinov, D.D. Huang, A. Zhukov, J. Ho, and H. S. Kwok, *Jpn. J. Appl. Phys.*, vol. 43 , p. 5440 (2004).

[2] E. Pozhidaev, V. Chigrinov, and X. H. Li, *Jpn. J. Appl. Phys.*, vol. 45, p.875 (2006).

[3] Y. Ouchi, J. Lee, H. Takezoe, A. Fukuda, K. Kondo, T. Kitamura, and A. Mukoh, *Jpn. J. Appl. Phys.*, vol. 27, p.L1993 (1988).

[4] S. S. Bawa, A. M. Biradar, K. Saxena, and S. Chandra, *Appl. Phys. Lett.*, vol. 57, p. 1398 (1990)

[5] S. Kondoh, A. Suguro, K. Noguchi, K. lio, K. Ueda, N. Takahashi, M. Fujino, *International Display Workshops/Asia Displays'05*, LCT 6-1, p. 82(2005)

[6] A. Murauski et al, Sid'04 Digest, LP-8

[7] Khakhlou, A. Murauski, O. Yaroshchuk, E. Telesh, R. Kravchuk, *Journal of the SID*, vol 14, p. 257 (2006)

[8] V. L. Aristov et al, SID Int. Symp. Digest Tech. Papers 31, 811, 2000.

[9] V.G.Chigrinov: Liquid Crystal Devices: Physics and Applications (Artech House, Boston, London, 1999)

[10] X. Li, A. Murausky, A. Muravsky, H. L. Cheung, P. Xu, E. Pozhidaev, and V. Chigrinov, *Society for Info. Disp. Symp. Digest* vol. XXXVII, p. 883 (2006).

[11] E. P. Pozhidaev et al, V. G. Chigrinov, Y. P. Panarin and V. P. Vorflusev, Mol. Mat., vol 2, p. 225-238 (1993)